Maneuver Design and Calibration for the Genesis Spacecraft

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Extended Abstract

Genesis is the fifth mission selected as part of NASA's Discovery Program. The objective of Genesis is to collect solar wind samples for a period of approximately two years while in a halo orbit about the Earth-Sun L1 point. At the end of this period, the samples are to be returned to a specific recovery point on the Earth for subsequent analysis. This goal has never been attempted before and presents a formidable challenge in terms of mission design and operations, particularly planning and execution of propulsive maneuvers.

To achieve a level of cost-effectiveness consistent with a Discovery-class mission, the Genesis spacecraft design was adapted to the maximum extent possible from designs used on earlier missions, such as Mars Global Surveyor (MGS) and Stardust, another sample collection mission. The spacecraft design for Genesis is shown in Figure 1. Spin stabilization was chosen for attitude control, in lieu of three-axis stabilization, with neither reaction wheels nor accelerometers included. This precludes closed-loop control of propulsive maneuvers and implies that any attitude changes, including spin changes and precessions, will behave like translational propulsive maneuvers and affect the spacecraft trajectory. Moreover, to minimize contamination risk to the samples collected, all thrusters were placed on the side opposite the sample collection canister.

The orientation and characteristics of thrusters are indicated in Figure 2 and Table 1. For large maneuvers (>2.5 m/s), two 5 lbf thrusters will be used for Δv, with precession to the burn attitude, followed by spin-up from 1.6 to 10 rpm before the burn and spin down to 1.6 rpm afterwards, then precession back to the original spin attitude. For small maneuvers (<2.5 m/s), no spin change is needed and four 0.2 lbf thrusters are used for Δv. Single or double 360° precession changes are required whenever the desired Δv falls inside the two-way turn circle (~0.4 m/s) based on the mass properties, spin rate and lever arm lengths based on thruster locations. In such instances, Δv resulting from spacecraft precession cannot be used effectively as a component of the desired Δv, and must therefore be removed by precessing at least one complete revolution around the turn circle. To eliminate cross-track execution errors, a second revolution in the opposite direction would also be performed.

This paper will address the design of propulsive maneuvers in light of the aforementioned challenges and other constraints. Maneuver design will be performed jointly by the Navigation Team at JPL and the Spacecraft Team at LMA, based on the process indicated in Figure 3. Typical maneuver timelines will be presented which address considerations introduced by attitude changes. These include nutation, which is introduced by precessing or spinning down and must be given sufficient time to damp out prior to execution of subsequent events, as well as sun and earth pointing constraints, which must be considered to ensure sufficient spacecraft power and to minimize telecommunications interruptions, respectively.

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The paper will include a description of how individual propulsive maneuvers are resolved into components to account for Δv from translational burns and spacecraft attitude changes required to carry out such maneuvers. Contributions to maneuver Δv arising from attitude changes, based on mass properties for the period just after launch, are indicated in Figure 4. Similar curves will be presented spanning all mission phases from launch through return. A set of closed-form equations for resolving maneuver components, based on a specific Δv required for correction or deterministic changes to the spacecraft trajectory, will be presented, as well.

In addition to nominal maneuvers, special calibration maneuvers are planned to improve open-loop modeling of maneuvers and to reduce execution errors. Uncalibrated execution errors are indicated in Table 2. Such errors could be reduced by 50% or more over the course of the mission. Special calibrations are of particular importance for the return leg of the mission, since the sample canister must be returned to a specific location within the Utah Test and Training Range (UTTR) for mid-air retrieval. An entry angle tolerance of no less than ±0.08° is required to achieve this objective. Biasing of the final return maneuvers coupled with a specific maneuver mode to use a series of well-characterized spin changes to effect these maneuvers is part of the current Genesis baseline mission plan.

Another important objective of calibrations is to better characterize precession maneuvers. Such maneuvers are part of most propulsive maneuvers, but are also required periodically to maintain sun-pointing for power or daily during solar-wind pointing during collection periods. Although relatively small, such maneuvers will have a significant cumulative impact on orbit determination, particularly in the halo portion of the mission. The current mission design also calls for three stationkeeping maneuvers during each halo orbit of approximately six months duration. These stationkeeping maneuvers may be sufficiently small that single or double 360° precession changes may be required.

Because there are no accelerometers on board the spacecraft, calibration can only be performed with the aid of ground-based radiometric tracking. To establish a high degree of accuracy in characterizing the magnitude of burns, the spacecraft spin axis should be along the line of sight to the Earth, providing Doppler measurements with <1 mm/sec accuracy in S-Band. Mission constraints allow such alignment only during certain portions of the mission when the Earth-spacecraft-sun geometry is favorable. The impact of precessions, or burns at times when geometry is not favorable, can be assessed by reconstruction of the spacecraft trajectory using tracking arcs of several days before and after the event. Plans for special calibration maneuvers in the context of other maneuvers planned to date will be discussed.

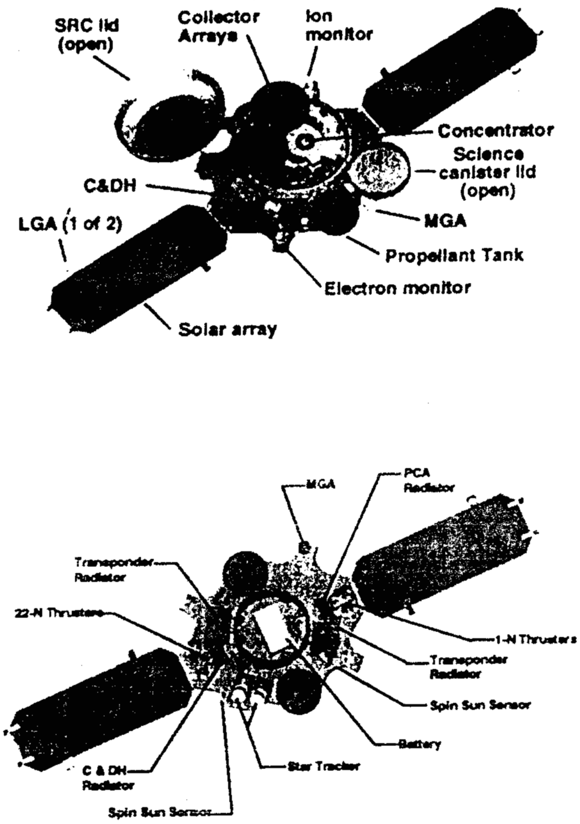

Figure 1. Genesis Spacecraft

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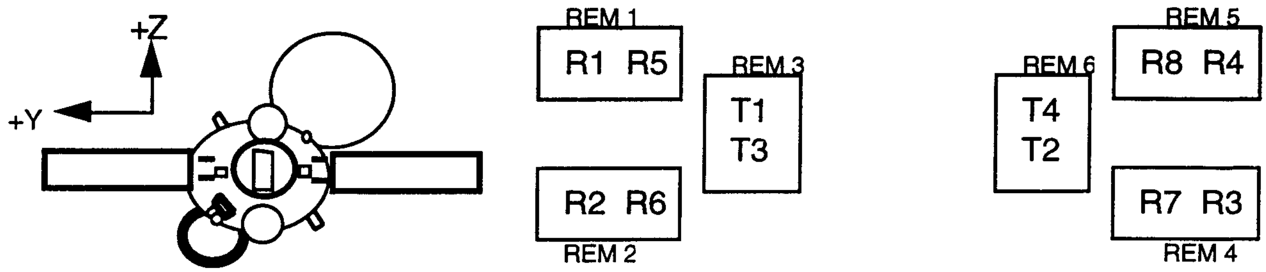
Table 1. Thruster Combinations Used During Mission

Side A (Primary String)	Side B	Usage
R1,R2,R3,R4	R5,R6,R7,R8	$\Delta v < 2.5$ m/s
R1,R2 and/or R3,R4	R5,R6 and/or R7,R8	Nominal precessions
R2,R4	R6,R8	+X spin up
R1,R3	R5,R7	+X spin down
T1,T2	T3,T4	$\Delta v > 2.5$ m/s
T1 and/or T2	T3 and/or T4	Rapid precession (EOL)



NOTES:

All thrusters are located on the aft (-X) side, which usually faces away from Sun and towards Earth.

T refers to the large 5 lbf thrusters and R refers to the small 0.2 lbf thrusters. The T thrusters have their thrust axis toward +X. The R thrusters are canted 45° off -X in the X,Z plane.

For precession maneuvers, one can use a single set, e.g., R1 and R2, once a spin cycle, or two sets, e.g., R1,R2 and R3,R4, in alternating half cycles for faster precessions. Faster precessions usually mean greater nutation at the end of precession.

Figure 2. Thruster Configuration

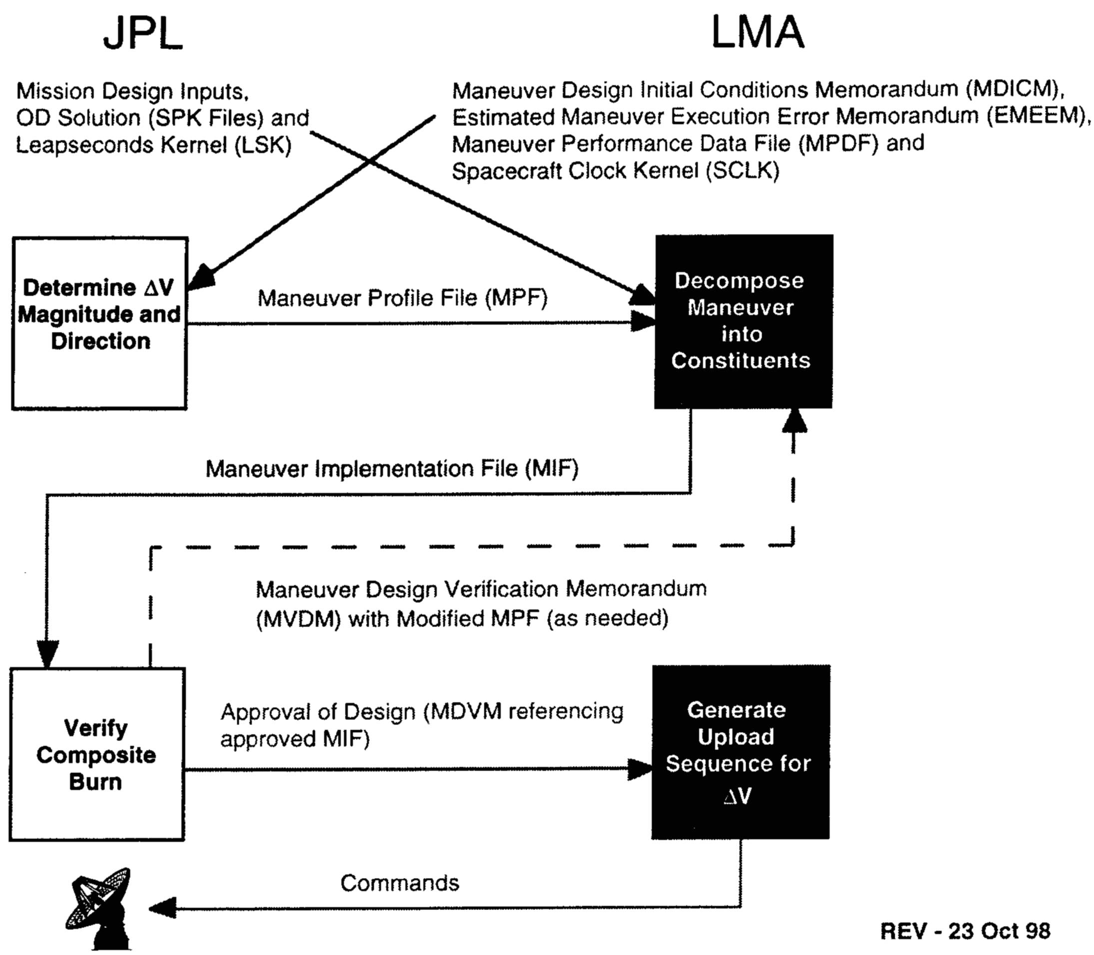
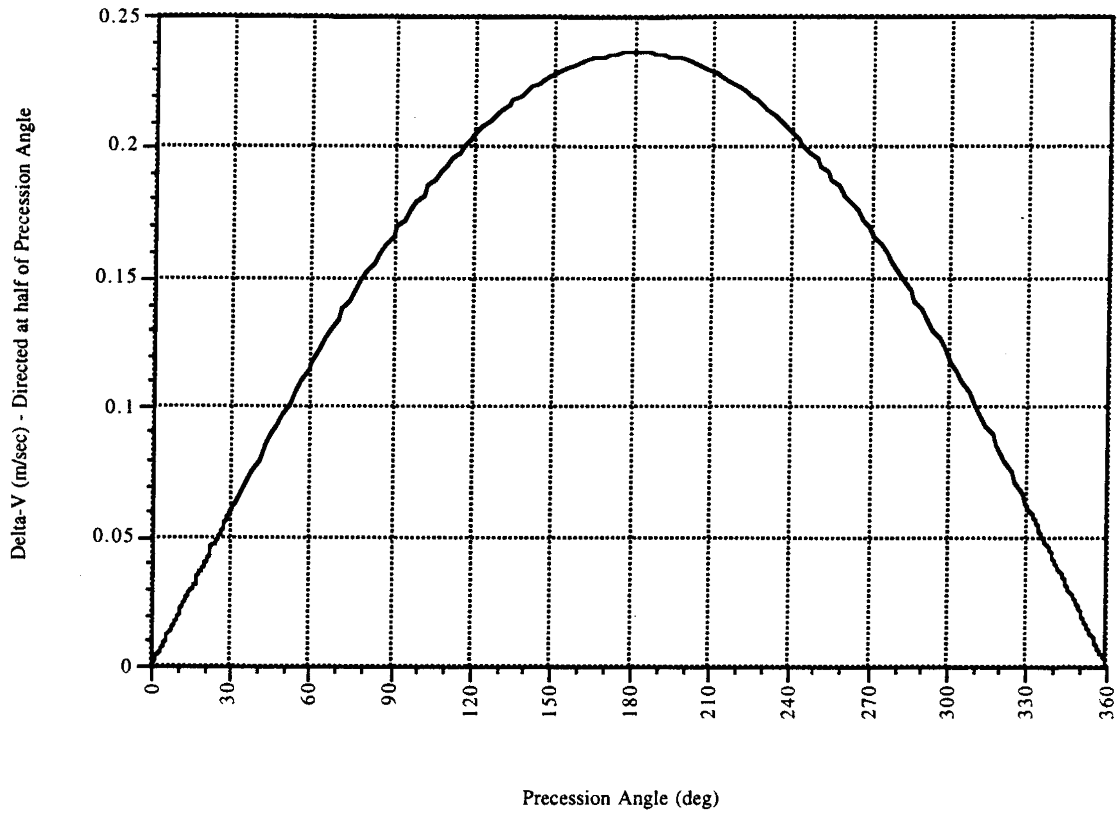


Figure 3. Maneuver Design Process



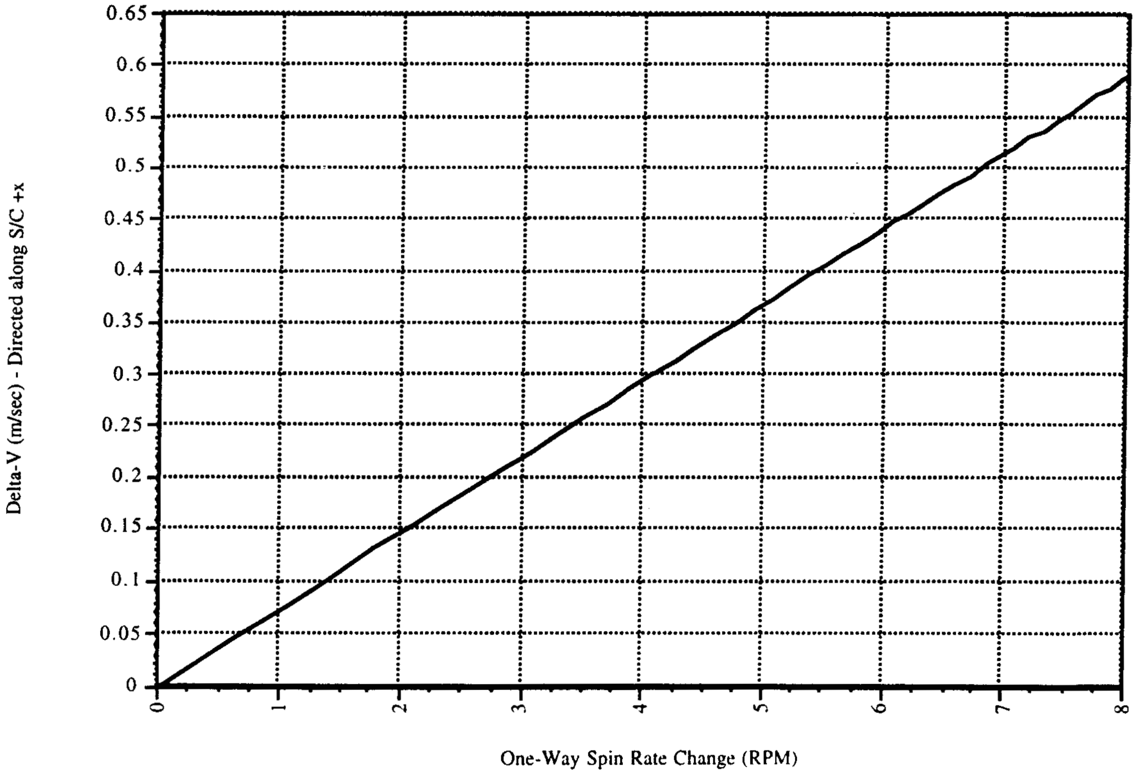


Figure 4. Contributions to Δv Due to Attitude Changes (Precessions and Spin Rate Changes)

Table 2. Uncalibrated Maneuver Execution Errors

Maneuver Component	Error (Fixed)
Small Angle Precession ($\leq 10°$; error applies one way for pointing corrections)	≤ 0.0002 m/s (3σ) per axis per degree of precession
Large Angle Precession **a)** $>10°$ and $\leq 180°$ (error applies for entire two-way precession)	≤ 0.04 m/s $\times$ (1-way precess angle/180°) (3σ) along original spin pointing direction; ≤ 0.03 m/s $\times$ (1-way precess angle/180°) (3σ) per crosstrack axis with respect to original spin pointing direction
b) Translational Δv inside turn circle (360° plus reverse 360°; error applies for entire 720° precession)	≤ 0.01 m/s (3σ) per axis
Spin Change (error applies to total of up and down spins)	≤ 0.06 m/s $\times$ (spin change/16 rpm) (3σ) along spin axis; ≤ 0.01 m/s $\times$ (spin change/16 rpm) (3σ) per crosstrack axis
Translational Δv Manuever (after precession/spin-up and before spin-down/precession)	*Less than values indicated below.* Initial nutation angles are $\leq 10°$; for $\Delta v < 2.5$ m/s and SRC closed, assumes end of life (EOL) performance in terms of mass properties and propulsion performance†

Translational Δv Usage criteria	**Thrusters**	**Magnitude proportionality %**	**Fixed magnitude m/s**	**Crosstrack proportionality % (per axis)**	**Fixed Crosstrack m/s (per axis)**
Δv > 2.5 m/s; SRC closed	two 5 lbf	6.0	0	2.0	0
0.05<Δv<2.5 m/s; SRC open	four 0.2 lbf	6.0	0.01	4.0	0.005
0.05<Δv<2.5 m/s; SRC closed†	four 0.2 lbf	6.0	0.01	2.0	0.003